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# Self-Diffusion Slowdown in Liquid Indium and Gallium under Confinement

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## 1. Introduction

When liquids are embedded into nanoporous matrices their physical properties can be affected by confinement conditions. In particular, the self-diffusion process within nanopores was shown to alter noticeably compared to bulk for many inorganic and organic liquids. Our recent NMR studies showed that atomic mobility in liquid indium and gallium embedded into nanoporous matrices is also strongly influenced by confinement leading to drastic slowdown of self-diffusion compared to that in bulk melts. The slowdown of atomic mobility manifests itself as acceleration of nuclear spin relaxation for confined liquid indium and gallium caused by enhancement of the quadrupole contribution to total relaxation.

## 2. Experimental results and discussion

The sample under study consisted of nanoporous matrices (porous glasses and artificial opals) filled with gallium and indium under elevated pressure. Nuclear spin-lattice relaxation was measured for the $^{115}$In, $^{69}$Ga and $^{71}$Ga isotopes in confined metallic melts using the inversion recovery technique. The NMR linewidth was also measured to estimate the rate of transverse relaxation.

The $^{115}$In longitudinal magnetization restoration curves obtained at 415 K for the opal and porous glass samples are shown in Fig.1 as an example. At that temperature the indium on the sample surface remains solid. Fig.1 shows also the restoration curve for bulk indium obtained at 430 K. The remarkable enhancement of spin-lattice relaxation for confined indium compared to relaxation in bulk is seen in Fig.1. For the opals the relaxation rate increased more than by a factor of four [1]. The relaxation acceleration is even more pronounced for indium within the porous glass. Similar relaxation acceleration was seen for confined liquid gallium [2].

It is known that spin relaxation in liquid non-transition metals for nuclei with spin $I>1/2$ occurs mainly due to two independent contributions – the interaction of the nuclear magnetic moment with conduction electrons and the interaction of the nuclear quadrupole moment with electric field gradients produced by atomic motion in melts. The relative effectiveness of the contributions depends, in particular, on the value of nuclear quadrupole moments and on the correlation time of atomic motion. For liquid gallium the two contributions were separated due to measurements of spin relaxation for two isotopes with different magnetic and quadrupole moments. For indium, the magnetic contribution

for the opals and porous glass was implied to remain unchanged on the base of the Korringa relation and the Knight shift, which coincided with that in bulk within the experimental accuracy limits. For both indium and gallium melts, the relaxation acceleration was ascribed to the enhancement of the quadrupole contribution. This allowed us to estimate the increase in the correlation time of atomic mobility in confined melts. Self-diffusion slow-down was noticeable also for liquid indium and gallium on the surface of the samples and for particles of several microns in size.

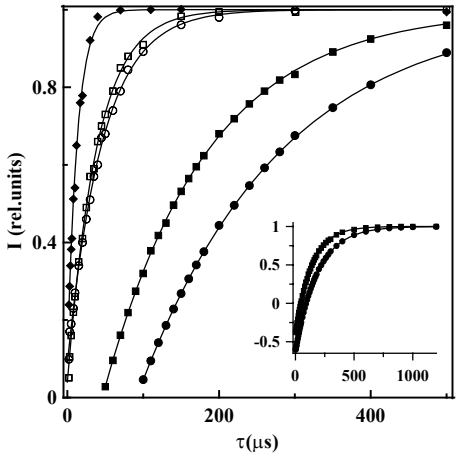


Fig. 1. $^{115}$In longitudinal magnetization recovery curves ($\tau$ is the time between first and second pulses) for melted indium embedded into the porous glass (closed diamonds), two opal samples (open circles and open squares), for bulk liquid indium (closed circles), and for melted indium on the surface (closed squares). The inset shows full recovery curves for bulk and surface liquid indium. Solid lines are single exponentials.

## 3. Conclusion

The spin relaxation times for the $^{115}$In isotope in liquid indium and $^{69}$Ga and $^{71}$Ga isotopes in liquid gallium embedded into artificial opals and porous glasses were found to be shortened remarkably compared to the bulk indium and gallium melts. The spin relaxation acceleration was ascribed mainly to the enhancement of the quadrupole contribution caused by the translational diffusion in liquid metals, the magnetic contribution was implied unchanged on the base of data for two gallium isotopes, the Knight shift measurements and the Korringa relation. Calculations made for quadrupole relaxation showed that it dominated the spin relaxation process for indium and gallium in nanopores and that the correlation times of atomic motion increased drastically depending on pore sizes. The increase in the correlation time evidenced a strong slowdown of self-diffusion for confined melted indium and gallium.

## References

[1] E.V. Charnaya, T. Loeser, D. Michel, C. Tien, D. Yaskov, Yu.A. Kumzerov, Phys. Rev. Lett. **88** (2002) 097602.

[2] E.V. Charnaya, C. Tien, Yu.A. Kumzerov, A.V. Fokin, Phys. Rev. B **70** (2004) 052201.

[3] C. Tien, E.V. Charnaya, P. Sedykh, Yu.A. Kumzerov, Phys. Solid State **45** (2003) 2352-2355.